THE INFLUENCE OF FINE AGGREGATE COMBINATIONS ON PARTICLE SIZE DISTRIBUTION, GRADING PARAMETERS AND COMPRESSIVE STRENGTH OF SANDCRETE BLOCKS

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Abstract: The current extensive use of low priced fine aggregate (sand) deposits employed in sandcrete block making in Nigeria is of concern because there appears to be a level of ignorance surrounding their existing properties and implications. To this end, silt contents and some grading parameters of the most commonly used fine aggregate deposits in parts of Midwestern Nigeria (Benin City), like the co-efficient of uniformity (C_u), curvature co-efficient (C_c) and the fineness modulus (F_m) were experimentally derived to ascertain these basic properties. In addition, the strength and durability properties of sandcrete blocks made from these sands were also established. It reveals that the low priced sands exhibited poorer properties in comparison to the more expensive sand. As a way of improving the properties of these frequently used low priced sands, a combination approach was adopted between the weaker and commonly used sands with those that are more expensive and less frequently used. Findings revealed that the approach of combining the two created significant improvement in compressive strength, durability and grading parameters of low priced sands with only marginal impact on cost.

Keywords: *Fine aggregates, uniformity coefficient, curvature coefficient, fineness modulus, compressive strength, durability, silt contents, Nigeria.*

1. INTRODUCTION

The prevalence of poor quality control and the use of sub-standard building materials have been attributed as causal factors responsible for the high failure rates of buildings in Nigeria (Okpalla and Ihaza 1987; Okolie and Akagu 1994; Alutu 2000). Furthermore, Illston et al. (1979) as reported by Nwokoye (1999) also argued that structural failure is directly related to constituent material failures and the material to material interactions within the structural unit. Hence, improving constituent materials of any structural unit ultimately enhances its overall properties and value.

It is further argued, from investigations, that the perennial failure rates of the most widely applied precast units i.e. sandcrete[i] blocks in the Nigerian construction industry depends on factors which include substandard materials, poor workmanship and poor control of the production process (Florek 1985; Aria 1995[ii]; Abieyuwa 1998[iii]; Olaniyi 2000[iv]; Usiwo 2000[v]). Consequently, these sandcrete blocks frequently fail to meet load-bearing specification standards recommended by the Nigerian Federal Ministry of Works (Okpalla and Ihaza 1987). It is not surprising therefore, to see cracks in most walls constructed using some of these precast units or the reoccurring cases of collapse under self weight of some of these blocks while being transported. These physical observations have prompted masonry studies within the country and findings have confirmed suspicions about their inadequacies.

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[i] Sandcrete is a composite material consisting of fine aggregate (sand), cement and water at appropriate ratio. The material could be used in the manufacture of blocks and also as a binder for precast units in its early stages i.e. before it sets and hardens. On setting and hardening, the blocks attain sufficient strength to be used as a walling material.

[ii] Aria, O. A. 1995. The strength of sandcrete blocks made from different sand deposits. Civil Engineering department, University of Benin, Nigeria.

[iii] Abieyuwa, O. 1998. Investigation on the strength of sandcrete blocks produced and marketed in Ekpoma town. Edo state University, Nigeria.

[iv] Olaniyi, L. M. 2000. Compressive strength of Marketed sandcrete hollow blocks in Warri. Civil Engineering department University of Benin, Nigeria.

[v] Usiwo, I. J. 2000. Compressive strength of marketed sandcrete blocks in Effurun. Civil Engineering Department, University of Benin, Nigeria.

2. BACKGROUND

Masonry studies in, for example, Enugu, a city in the eastern part of Nigeria revealed that none of the tested 84 sample blocks (450X225X225) selected by random sampling at the 28 day crushing test met the minimum standard strength of 1.7N/mm^2 (Okolie and Akagu 1994). Moreover, the strength of the samples varied from one block industry to another and similar strength variations were noticed even within samples from a single source (block industry). A total of 25 block moulding industries were used for this investigation.

In a similar study carried out in midwestern Nigeria (Benin City), Okpalla and Ihaza 1987 revealed that only 21 percent of the tested sample blocks had strength values up to or greater than the required mean strength of 2.1N/mm^2. However, 52 percent met the minimum strength requirement of 1.7N/mm^2 but the remaining 27 percent failed to meet the minimum strength requirement. A total of thirty block moulding industries were randomly selected for the Benin City investigation. Nonetheless, masonry studies carried out in another town within the Midwestern part of Nigeria (Ekpoma) and its environs revealed a total of 95 percent of the tested block samples failed to meet the minimum standard requirements of 1.7N/mm^2 (Abieyuwa 1998). Furthermore, similar results were obtained at Ughelli, Effurun, and Warri towns in Midwestern Nigeria.

Investigation in Ughelli and Warri towns revealed that none of the tested blocks samples in each of these towns met the standard minimum requirement of 1.7N/mm^2 (Clarke 2000[vi]; Olaniyi 2000). Not less than twenty block moulding industries were used for this

[vi] Clarke, P. O. 2000. Investigation on the compressive strength of hollow blocks produced in Ughelli. Department of Civil Enginering, University of Benin, Nigeria.

investigation. In addition, only 13 percent of the tested blocks samples in Effurun at the 28 day crushing test met the minimum standard requirement.

Investigation in six northern states of Nigeria (Florek 1985; Okpalla and Ihaza 1987; Usiwo 2000) confirmed that the blocks produced in the Northern part of Nigeria were of very low quality. A total of 306 block samples were used for this investigation.

Over all, the investigations carried out revealed that, the use of silt-laden fine aggregate, inadequate compaction, wrong mix proportions, high water/cement ratio and inadequate or uncontrollable curing conditions were identified as being responsible for the low strength values obtained. With the exception of silt laden aggregate, the other factors fall under poor workmanship and poor supervision of the production process. Moreover, the use of silt laden fine aggregate is currently on the increase because it is more easily affordable. The current widespread use of silt laden fine aggregate (low priced fine aggregate) deposits employed in sandcrete block production in Nigeria has reached worrying levels in view of the inadequate knowledge of their existing properties and usage implications.

However, there is a need to optimize the utilization of this low priced fine aggregate, bearing in mind its economic advantage. Such a goal could only be achieved if there is a proper understanding of their properties, extent of economic value and possible ways of improving them. Furthermore, currently no standards exist on the optimum utilization of locally available fine aggregate that have very poor in properties; also there are no known standards established for the various fine aggregate deposits found in Nigeria (Omoregie 2002[vii]). For this reason good quality sands could be easily discarded in favour of poor quality ones which

[vii] Omoregie, A (2002). The influence of fine combinations and vibration time on the compressive strength of sandcrete blocks in Benin City (An M.Eng thesis). Civil Engineering department. University of Benin, Nigeria.

are usually cheaper (Omoregie 2002). However, the establishment of such standards in Nigeria would require huge research that would investigate every sand deposit found in each town and city in the country.

3. PROGRAMME

In order to pioneer the process, this investigation has been limited to fine aggregate found in Benin City, a city in the midwestern part of the country. Subsequently, some grading parameters of the most commonly used fine aggregate deposits found in Benin City such as the co-efficient of uniformity (C_u), curvature co-efficient (C_c) and the fineness modulus (F_m) were derived by laboratory test with the aim of ascertaining those fine aggregate employed in sandcrete block production that are properly or poorly graded. In addition, the strength and durability properties of sandcrete blocks made from these sands under proper supervision were also established. As a way of improving the properties of these frequently used low priced sands, they were blended or combined with those that are more expensive and less frequently used.

The Benin City investigation was carried out on the following sand deposits:

- Okhuahia river sand (OKRS)
- Okhuahia erosion sand (OKES)
- Ovia river sand (OVRS)
- Ovia erosion sand (OVES)
- Okhoro erosion sand (OES)
- Ikpoba flood erosion sand (IFS).

In this paper, more emphasis was placed on results obtained from OKRS, OVRS, OES and IFS and their various combinations because OKRS and OVRS were the most expensive and less frequently used sands while OES and IFS were the least expensive and commonly in use. The properties of OKES and OVES fell in-between the more expensive sands on one hand and the less expensive sands on the other. However, the primary aim of this paper was to improve the weakest and most commonly used sands by blending with the best and less frequently used sands.

4. METHODOLOGY

- **Sampling of fine aggregate:** The Riffler process was adopted as the sampling method for this investigation. (Neville and Brooks 1994; Jackson and Dhir 1996).
- **Sieve analysis:** The particle size distribution was carried out mechanically through a stack of British standard sieves as described in BS 1377 (1990): Parts 1 and 2. This process was conducted for all the sands and the various sand combinations in order to understand their grading and improvements due to sands combinations. Some of these improvements are represented as curves on the conventional semi-logarithmic plot (Figures I, II, III, and IV). Finally, the grading for the various sands and their relative combinations were numerically expressed in terms of grading coefficients like the uniformity coefficients (C_u), curvature coefficients (C_c) and the fineness modulus (F_m) (Table VI).

  The uniformity coefficient (C_u) defines the steepness of the curve on semi-logarithmic plot and its value ranges from less than or equal to 2 for poorly graded sand to greater than or equal to 5 for a well graded sand (Jackson and Dhir 1996). While the mid portion of the curve which defines the possibility for a dense packing is measured by Curvature coefficients (C_c) and its value ranges from 1 to 3 (Jackson and Dhir 1996; Terzaghi et al 1996). However, fineness modulus (F_m) is the sum of all the cumulative percent retained from British standard sieve 150µm to 2.36mm divided by 100 and the coarser the material the higher the fineness modulus (Illston and Domone 2001). Fineness modulus for a well graded sand ranges from 2.25 to 3.25.

- **Silt content test:** this was carried out using the standard decantation (field settlement) method.
- **Sandcrete block production:** The sandcrete blocks were produced under highly controlled conditions. The mix ratio adopted was ratio 1:6 (i.e. one part cement to six parts sand). The optimum moisture content from the compaction test conducted and the actual moisture content of the various sands were derived in accordance with the procedures in BS 1377: Part 2. Thus, the actual proportion of water added to the mix was the difference between the optimum moisture content and the actual moisture content of the sand. This was carefully done in order not to exceed the optimum moisture content of the sand. However, the water/cement ratio employed was 0.80. This was because the derived water/cement ratio for individual sands all roughly approximated to 0.8 and all batching was carried out by mass. A practical example is as follows:

  At a mix ratio of 1:6 (i.e. one part cement to six parts sand), a 100kg of sand would give 16.3kg of cement.

  Thus, Bulk weight = 100 +16.3 = 116.3kg

  Optimum moisture content obtained from compaction test for OKRS = 11.21%.

  Therefore mass of water = (11.21 x 116.3) / 100 = 13.04kg.

  Actual moisture content in OKRS obtained from test = 0.84 %

  = (0.84 x 100) / 100 = 0.84g

  Proportion of water added to the mix = 13.04 – 0.84 = 12.20g

  However, water/cement ratio = 13.04 / 16.3 = 0.8

- **Compressive strength test:** Both the dry[viii] and wet[ix] compressive strength tests were carried out using the destructive test method. The compressive strength tests were carried out in accordance with BS 6073 (1981): Part 1. For the test programme conducted (number of blocks tested per sand and the various sands combinations) please see Tables I , II, and III below:
- **Durability test:** the durability test was the shower spray method. The aim is to assess the resistance of the block to the effects of storm or driving rain i.e. above 508mm of annual rainfall (Awoleye 1985[x]; Fitzmaurice 1958). This was achieved by subjecting the block samples to 1.5 kg/cm^2 (22psi) pressure of water for two hours. It was carried out with a 100mm diameter shower head clamped vertically above the block. The block was weighed and turned side ways i.e. its largest face in the horizontal position and at a distance of 200mm from the showerhead. Finally, a visual inspection and weighing was carried out to ascertain the extent of pitting and weight loss.

5. DISCUSSION

From the compressive strength results tables and the plotted graphs for all the various sand samples (i.e., Okhuahia river sand (OKRS), Ovia river sand (OVRS), Okhuahia erosion sand (OKES), Ovia erosion sand (OVES), Ikpoba flood erosion sand (IFS) and Okhoro erosion sand (OES)); their highest compressive strengths were recorded at the 28-day crushing test (Table VI and Figure V). Nonetheless, OKRS gave the highest compressive strength at 7-day, 14-day and 28-day respectively. Second in hierarchy was OVRS; this was followed by OKES and then OVES. However, the last two: IFS and OES

[viii] The dry compressive strength test is the compressive strength test carried out on the blocks after the 28 day curing period.
[ix] The wet compressive strength test is the test conducted after the 28 day cured blocks are submerged in water for another 14 days before undergoing the compressive strength test.
[x] Awoleye, O.A. (1985). Soil stabilised compressed blocks for Civil engineering works (An M.Eng thesis). Department of Civil Engineering, University of Benin, Nigeria.

had compressive strength values that were much lower compared with the likes of OKRS, OVRS, OKES, and OVES. However, OES recorded the lowest compressive strength.

The silt content test results revealed that OES had the highest percentage silt content. This was followed by IFS and then OVES, OKES and OVRS. OKRS silt content test result was the least (see Table VI and Figure VII). Nevertheless, none of the sands exceeded the minimum allowable percentage silt content.

From the particle size distribution test (i.e. sieve analysis) carried out to ascertain the grading parameters of each of these sands; it was revealed that OKRS was the best sand in comparison to the others (Table VI, and Figure I and II). Generally, the grading performance of each of these sands was similar to their relative positions or performance during the compressive strength test. For example, the grading performance of OES was poor because it was much finer (i.e. high silt content) in comparison to the others (Table VI and Figure II, V and VII). This had led to an increase in the water / cement ratio for a given workability which in turn had reduced the compressive strength. Thus, strength is partly related to the level of silt content in sands. It is 'partly related' because several other factors outside constituent materials affects strength i.e. method of preparation, curing and test conditions (Jackson and Dhir 1996; Neville and Brooks 1994; Neville 1996)

The marginal silt content, best grading parameters and compressive strength of sandcrete blocks exhibited by OKRS (Table VI and Figure I, II, V and VII), exposed OKRS to be the best sands around and within Benin City. However, this cannot be said of OES that have exhibited poor grading parameters, compressive strength and much higher silt content (Table VI and Figure II, IV, V, VI and VII). Not withstanding, OES is still the most widely used sand in Benin City and its environs because it is readily available and cheap.

In the bid to maximize the utility value of both OKRS and OES, a combination approach was employed vis-à-vis: OES (highest in silt content) combined with OKRS (least in silt content) at ratio 1:1, 2:1 and 1:2. Similarly, OKRS AND IFS were blended together at the same ratios and these were repeated for OVRS combining with OES and IFS (Tables II, III and VI). The results were encouraging (Table VI and Figure III and IV).

Of particular interest was the combination of OKRS with OES and IFS where the wet compressive strength at 14-day test results was within the range of 37 percent to 41 percent less than their dry compressive strength values (Tables IV and VI). This comparison was necessary in view of the prevalent exposure conditions these blocks might be subjected to in future i.e. flooding resulting from natural occurrence and sometimes failed infrastructures. Information such as this would assist developers or builders on how to use these blocks. Most especially, in the riverine areas and water logged soils like the Niger-delta region of Nigeria. In addition, samples from these relative combinations i.e. OKRS and OES; OKRS and IFS yielded very high compressive strength increases over those of OES, IFS when used individually (Tables IV and VI). The range was over 99 percent to 103 percent for OKRS and OES blend alone (Table V). Surprisingly, the implication on cost of OKRS and OES combinations over OES samples at market value was just within the range of 8 percent to 11 percent increase (Table V). All samples from these combinations met the standard durability criteria having been subjected to the necessary test.

6. RECOMMENDATIONS:

- For an optimum utilization of fine aggregate like Okhoro river sand (OES) and Ikpoba flood erosion (IFS) sand in Benin City, we strongly recommend this combination approach with the much better sands like Okhuahia river sand (OKRS). It is our view that similar problems anywhere could be tackled using this combination technique.
- Having explored the structural properties of the combination approach; we are also of the view that further works needs to be carried out to ascertain the geotechnical properties of these combinations and its effects on the geotechnical properties of the individual fine aggregate.
- There is also the need to establish the optimum mix ratio of each combination as a guide to an optimum performance.
- Owing to the high failure rate of sandcrete blocks in the Nigerian construction industry, a body should be set up to monitor and enforce the quality control process of sandcrete block making in Nigeria.
- Finally, a lot of sensitization needs to be put in place as a way of educating stake holders in the business on the dangers associated with the usage of substandard building materials and products.

7. CONCLUSIONS:

Most frequently used sands in the Midwestern region of Nigeria are poorly graded and this has been responsible indirectly for the high failure rates of sandcrete blocks as poorly graded sand would require a high water / cement ratio. Thus, blending sands had improved successfully the use of these poorly graded sands and very significant benefit was achieved with only a marginal cost increase. We strongly recommend that the blending must not be carried out arbitrarily otherwise the set objectives will be defeated. Rather, it should be practically measured on site by mass or by volume since the cost of weighing machines are far beyond the reach of an average builder or developer in Nigeria. Finally, efforts should be geared towards knowing the actual moisture content and the optimum moisture content of the sand combinations to achieve the best water / cement ratio for an optimum performance as this information would assist to eradicate the fear of buckling in sand.

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Tables:

Table I: Number of blocks at the various testing periods for individual sands

Number of blocks at the various testing period				
Sand	7-day	14-day	28-day	Number of blocks per sand
OKRS	9	9	9	27
OVRS	9	9	9	27
OKES	9	9	9	27
OVES	9	9	9	27
OES	9	9	9	27
IFS	9	9	9	27
Total number of blocks tested				162

Table II: Number of blocks at the various testing period for each sand combination

Number of blocks at the various testing period					
Sand combinations	Ratio of mixture	7-day	14-day	28-day	Number of blocks per sand
OKRS and IFS	01:01	9	9	9	27
OKRS and IFS	01:02	9	9	9	27
OKRS and IFS	02:01	9	9	9	27
OKRS and OES	01:01	9	9	9	27
OKRS and OES	01:02	9	9	9	27
OKRS and OES	02:01	9	9	9	27
OVRS and IFS	01:01	9	9	9	27
OVRS and IFS	01:02	9	9	9	27
OVRS and IFS	02:01	9	9	9	27
OVRS and OES	01:01	9	9	9	27
OVRS and OES	01:02	9	9	9	27
OVRS and OES	02:01	9	9	9	27
Total number of blocks tested					324

Table III: Number of blocks at the 14-day testing period of some sand combinations for the wet compressive strength

Sand combinations	Ratio of mixture	14-day
OKRS and IFS	01:01	9
OKRS and IFS	01:02	9
OKRS and IFS	02:01	9
OKRS and OES	01:01	9
OKRS and OES	01:02	9
OKRS and OES	02:01	9
Total number of blocks tested		54

Table IV: Various OKRS combinations with OES, IFS and their wet and dry compressive strengths and percentage strength losses

Various OKRS Combinations With OES and IFS	Combination Ratio	Dry compressive Strength (N/mm^2) *d*	Wet compressive Strength (N/mm^2) *w*	% Strength loss $\left[\left(\frac{d-w}{d}\right)100\right]$
OKRS + OES	1:1	5.02	2.94	41.10
OKRS + OES	1:2	4.71	2.85	39.50
OKRS + OES	2:1	4.92	3.05	38.00
OKRS + IFS	1:1	5.25	3.20	39.50
OKRS + IFS	1:2	5.01	3.16	37.00
OKRS + IFS	2:1	5.69	3.44	39.50

Table V: Summary of percentage cost increment and compressive strength increments of various combinations of OKRS and OES over OES.

Various OKRS Combinations With OES	Combination Ratio	Production Cost (Naira)	% cost Increment over that of OES	Compressive strength Increments over OES (%)
OES	-	64.31	-	-
OKRS + OES	1:1	69.31	7.8	99.20
OKRS + OES	1:2	67.80	5.43	90.70
OKRS + OES	2:1	71.14	10.62	103

Table VI: Result of various sand and sand combinations grading parameters, silt content, compressive strengths and durability values

Sand and sand combinations	% Passing Sieve No. 25	Grading zone	Fineness Modulus (F_m)	Curvature Coefficient (C_c) $=\left(\frac{D_{30}^2}{D_{60}D_{10}}\right)$	Uniformity Coefficient (C_u) $=\frac{D_{60}}{D_{10}}$	Silt content %	Dry Compressive Strength (KN/mm^2)			Wet Compressive Strength (kN/mm^2) (28 days)	Durability test (% weight loss)
							28day	14day	7day		
OKRS	71.45	3	3.14	1.500	7.05	1.106	6.05	5.53	3.64	-	-
OVRS	85.20	4	3.09	1.350	2.11	1.512	5.59	5.39	3.54	-	-
OVES	81.99	4	2.81	3.350	5.90	1.630	5.02	4.88	3.18	-	-
OKES	77.80	3	2.95	1.540	3.81	1.860	5.28	5.14	3.34	-	-
IFS	86.20	4	2.45	0.420	6.00	2.264	2.57	2.10	1.79	-	-
OES	86.55	4	2.07	0.178	6.9	2.394	2.47	2.00	1.52	-	-
OKRS+OES (2:1)	56.91	2	5.18	1.120	5.24	-	4.92	4.88	3.37	3.05	2.20
OKRS+OES (1:2)	51.00	2	3.96	0.770	1.66	-	4.71	4.34	2.94	2.85	2.00
OKRS+OES (1:1)	57.00	2	4.22	0.901	3.12	-	5.02	4.84	3.13	2.94	2.15
OVRS+OES (2:1)	75.00	3	3.46	1.300	2.01	-	4.85	4.5	3.00	-	2.48
OVRS+OES (1:2)	71.00	3	3.48	1.090	2.61	-	4.45	4.00	2.80	-	2.31
OVRS+OES (1:1)	51.00	2	3.88	0.970	5.00	-	5.00	4.58	2.88	-	3.00
OKRS+IFS (2:1)	69.00	3	3.50	0.970	2.54	-	5.69	5.22	3.58	3.44	3.42
OKRS+IFS (1:2)	65.00	3	3.14	1.000	2.40	-	5.01	4.63	3.13	3.16	2.74
OKRS+IFS (1:1)	61.00	3	4.10	0.830	1.95	-	5.25	5.16	3.35	3.20	2.40

Where: D_{10} is the particle diameter at which 10% by weight of the sand is finer in size; D_{30} is the particle diameter at which 30% by weight of the sand is finer in size;

D_{60} is the particle diameter at which 60% by weight of the sand is finer in size; $F_m = \frac{total\text{ cumulative \% retained from sieve 2.36mm-150}\mu\text{m}}{100}$

Figure captions:

Figure I: Grading curve for OKRS on a semi-logarithmic plot.

Figure II: Grading curves for OKRS, OES and IFS on a semi-logarithmic plot.

Figure III: Grading curves for IFS and its various combinations with OKRS.

Figure IV: Grading curves for OES and its various combinations with OKRS.

Figure V: Compressive strength at 7, 14 and 28-day test for all the various sands.

Figure VI: Compressive strength at 7, 14 and 28-day testing period for OES and its Combinations with OKRS.

Figure VII: Silt content profile of all the various sands.

Figure I:

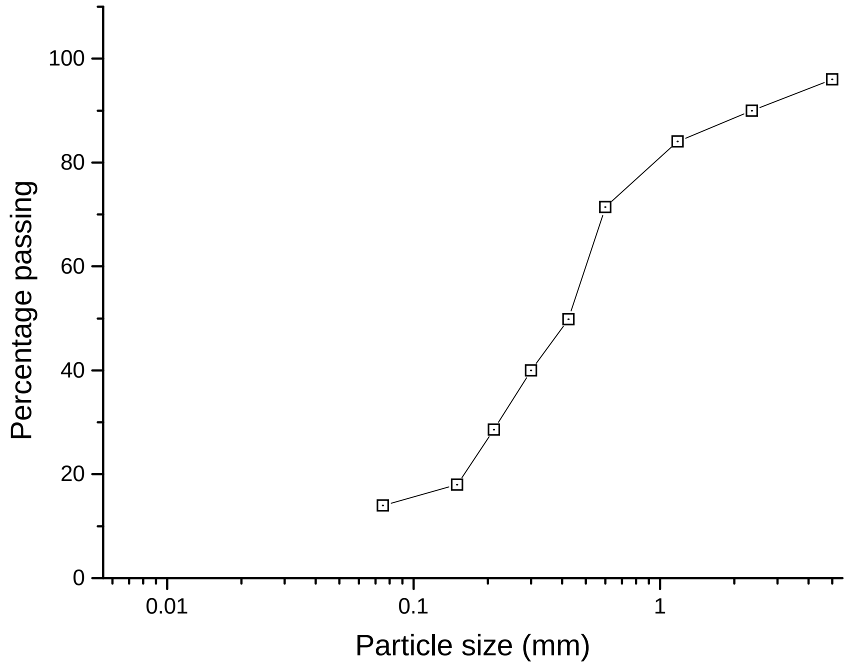
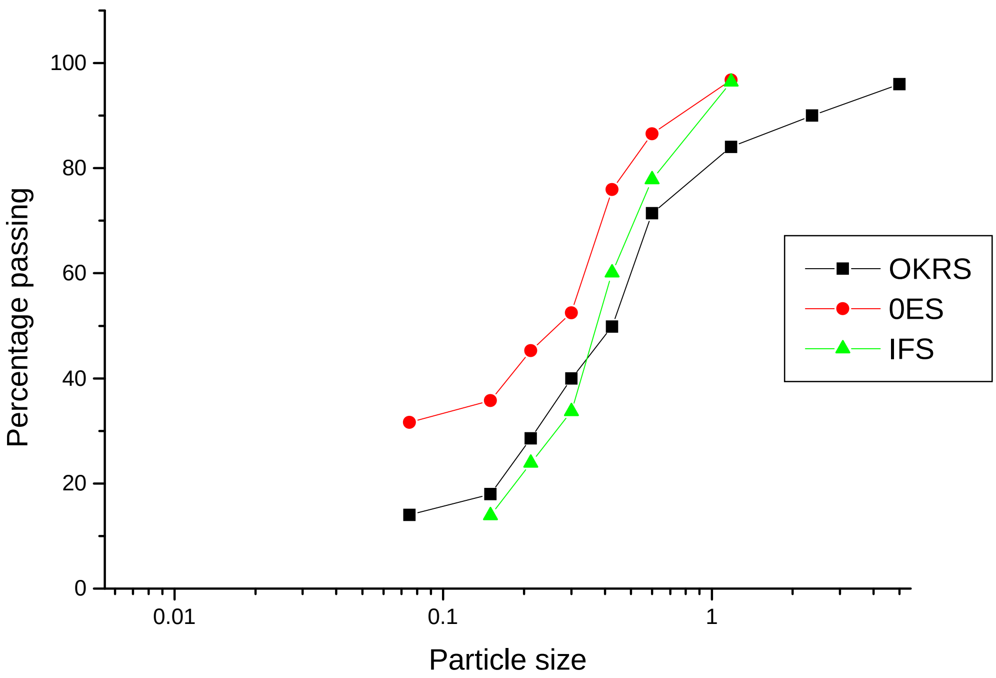
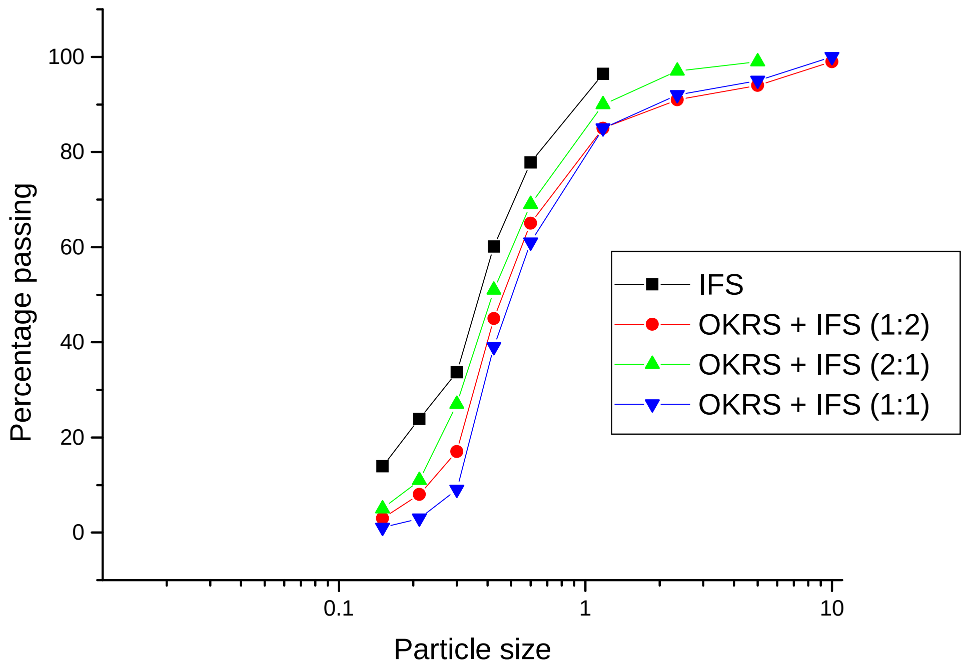


Figure II:



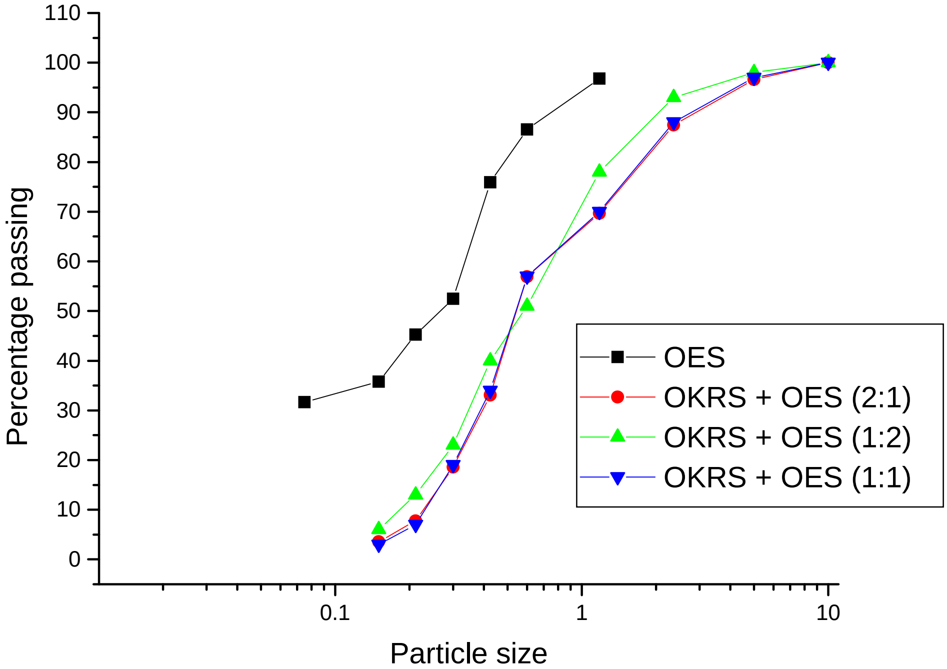
Percentage passing
100
80
60
40
20
0
0.01
0.1
1
Particle size
OKRS
0ES
IFS

Figure III:



100
80
60
40
20
0
Percentage passing
0.1
1
10
Particle size
IFS
OKRS + IFS (1:2)
OKRS + IFS (2:1)
OKRS + IFS (1:1)

Figure IV:


110
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Percentage passing
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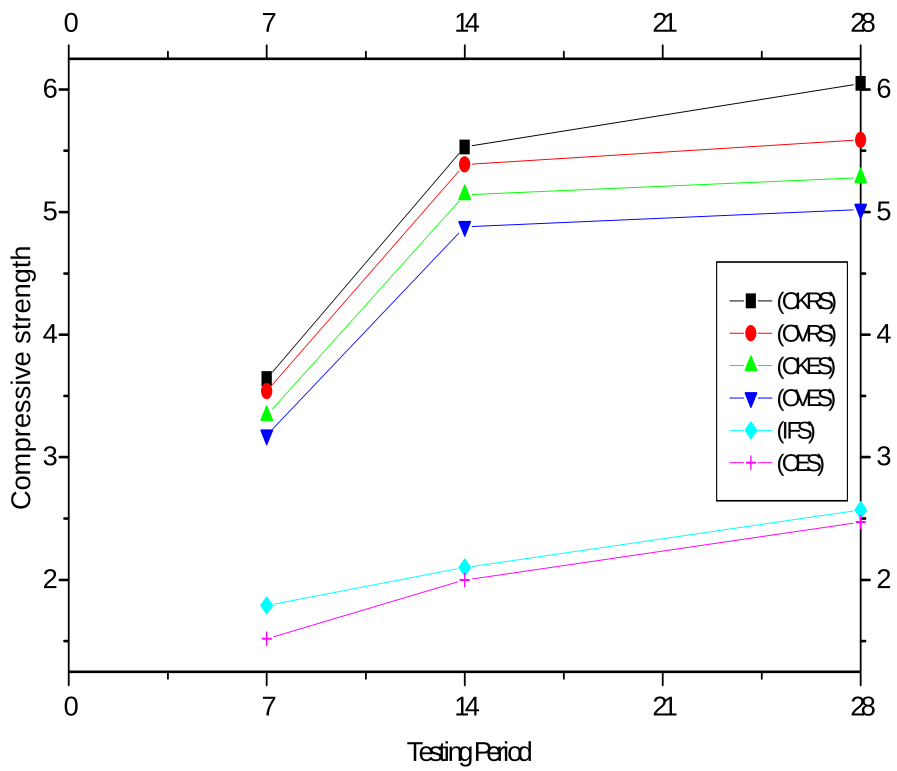
Particle size
OES
OKRS + OES (2:1)
OKRS + OES (1:2)
OKRS + OES (1:1)

Figure V:



0
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6
5
4
3
2
Compressive strength
(CKRS)
(OVRS)
(CKES)
(OVES)
(IFS)
(CES)
Testing Period

Figure VI:

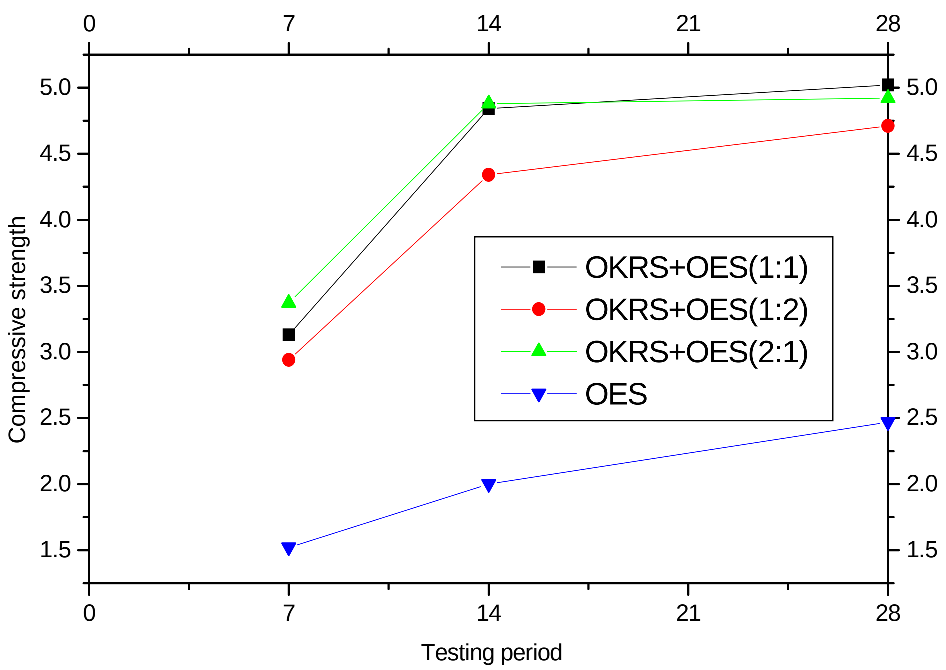
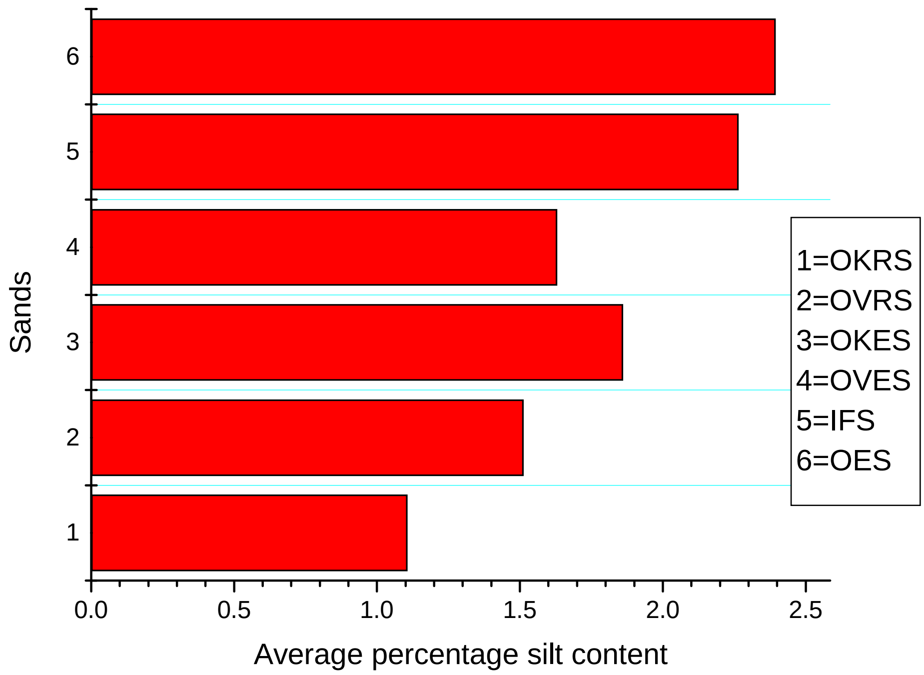

0
7
14
21
28
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
Compressive strength
Testing period
OKRS+OES(1:1)
OKRS+OES(1:2)
OKRS+OES(2:1)
OES

Figure VII:



Sands
6
5
4
3
2
1
0.0
0.5
1.0
1.5
2.0
2.5
Average percentage silt content
1=OKRS
2=OVRS
3=OKES
4=OVES
5=IFS
6=OES